SUPERCONDUCTIVITY

Topics to be covered -

→ What are superconductors ?
→ Critical Temperature
→ Difference between conductor and superconductor
→ Meissner Effect
→ Type I and Type II Superconductors
→ Applications of superconductors

Superconductors are the materials which are characterized by exactly zero resistance at extremely low temperatures and exclusion of the interior magnetic field.

Advantages of superconductors

① Electric current can flow through a superconductor without any energy loss, which greatly improves the efficiency of power transmission.

② Superconductors can generate very strong magnetic

fields, making them useful in MRI scanners and particle accelerators.

③ Due to meissner effect, superconductors can levitate above magnets.

④ These materials show improved performance of motors, generators because they eliminate resistive losses.

Disadvantages

① Most superconductors work only at extremely low temperatures, requiring expensive cooling systems.

② The materials, cooling systems and maintenance required for superconducting devices are expensive.

③ If the current exceeds the critical value, the material looses its superconducting property.

④ Many superconducting materials are brittle and difficult to manufacture into wires or practical shapes.

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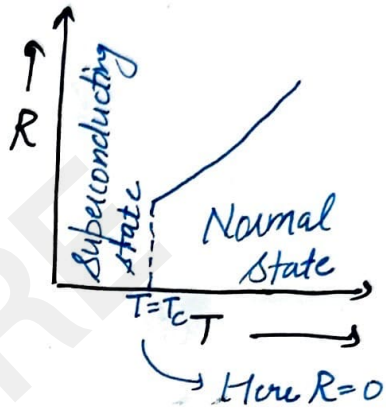
Critical Temperature (T_c)

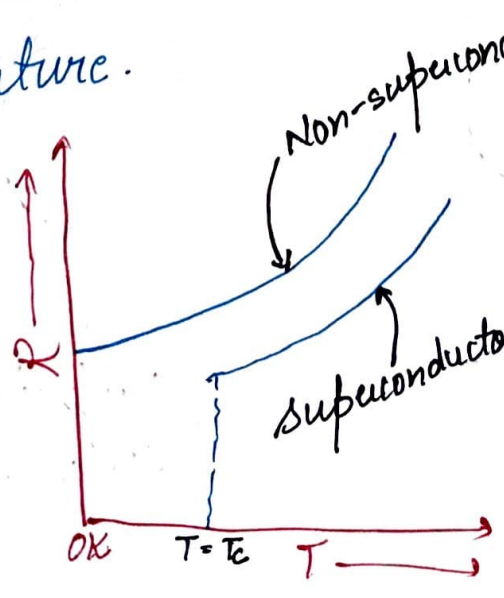
The temperature below which a material looses its electrical resistance and becomes superconducting, that particular temperature value is known as critical temperature.



Difference between Conductor and Superconductors

→ The resistance of a metallic conductor decreases gradually as temperature is lowered due to decrease of vibrational resistance of atoms. Even at absolute zero, a normal conductor has finite value of resistance.

→ In a superconductor, the resistance drops abruptly to zero when the material is cooled below its critical temperature.



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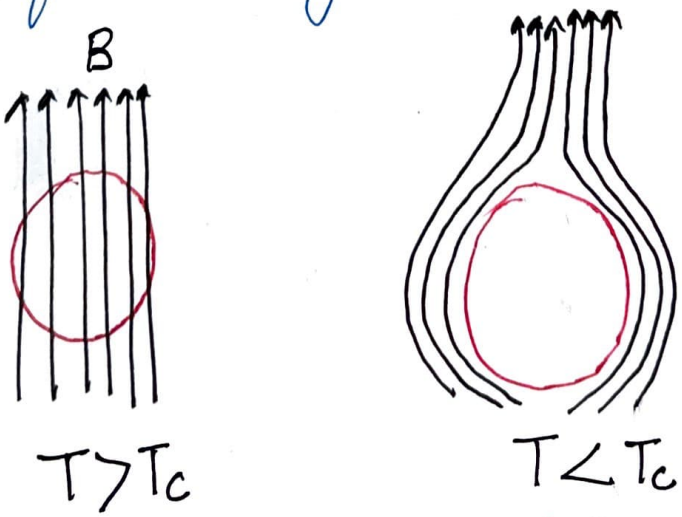
Meissner Effect

It is the phenomenon in which a superconductor expels all magnetic field lines from its interior when it is cooled below its critical temperature. As a result, the magnetic field inside the superconductor becomes zero.

→ The material becomes a perfect diamagnet.

Why?

When a material becomes superconducting (below its T_c), surface currents are induced in the material. These currents create a magnetic field that cancels the external magnetic field inside the superconductor, leading to perfect diamagnetism.



(Exclusion of magnetic field below T_c)

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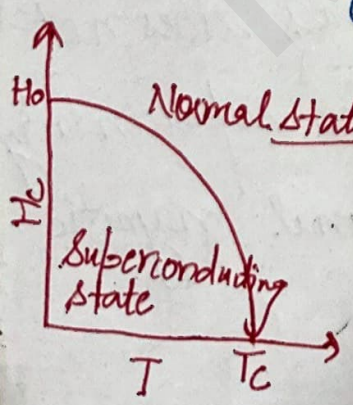
Effect of Magnetic field on superconductors

→ When a superconducting material is below its T_c, all magnetic field lines are expelled out [Meissner effect], the material is perfectly diamagnetic.

→ We can destroy the superconducting state by applying magnetic field. [Below T_c]

→ Critical magnetic field (H_c) is defined as maximum external magnetic field that a superconductor can withstand while remaining in the superconducting state. If the external field exceeds this value, the material looses its superconductivity and returns to normal conducting state.

→ The effect of magnetic field is given as –



$$H_c(T) = H_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$H_c(T)$ → critical magnetic field at T

$H_c(0)$ → critical magnetic field at $T = 0K$

T_c → critical temperature

Difference between Type I and Type II

Type I	Type II
① These are called as soft superconductors.	① These are called as Hard superconductors.
② These are low temperature superconductors.	② These are high temperature superconductors.
③ These materials are completely diamagnetic.	③ These are not completely diamagnetic.
④ No mixed state exists in Type-1 superconductors.	④ A mixed state exists in Type-II superconductors.
⑤ These materials obey the Meissner effect perfectly.	⑤ These obey the Meissner effect only partly.
⑥ These materials easily loose the superconducting state by low-intensity magnetic field.	⑥ These materials does not easily loose the superconducting state by external magnetic field.
⑦ There is a sharp change from superconducting to normal state at critical magnetic field value (H_c)	⑦ The transition from a superconducting to a normal state due to external magnetic field is gradual.

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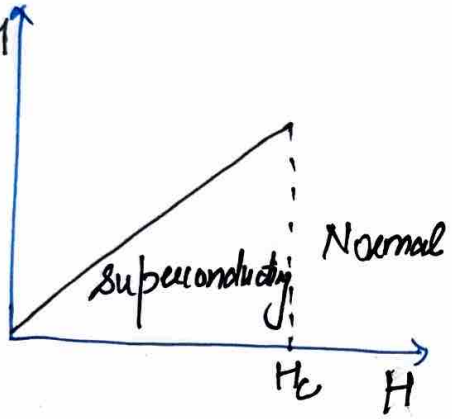
(8) There is only one critical magnetic field value.

(9) Ex: Lead, Mercury

(10)



(8) There are two critical magnetic field values (H_{c_1}) and (H_{c_2})

(9) Ex: Niobium-Titanium, Vanadium

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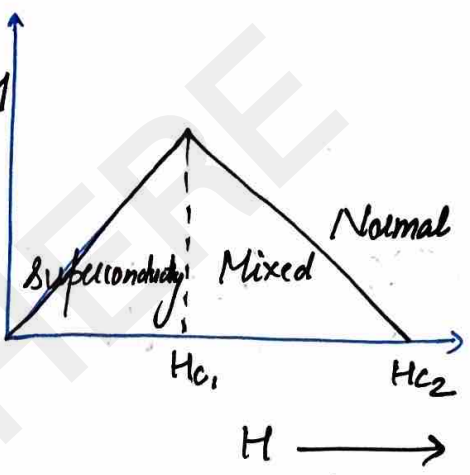

Advantages of Type I superconductors

(1) They show complete Meissner effect, meaning the material is perfect diamagnet

(2) Electric current can flow without any energy loss.

(3) There is no effect of slight impurity on superconductivity.

(4) They possess only one critical magnetic field(H_c), which makes their theoretical discription simpler.

(5) These consist of pure metals.

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Disadvantages of Type-I

(1) These loose superconductivity even in a small magnetic field.

(2) They becoming superconducting at very low temperatures.

(3) Due to critical low field, these are not useful for high-field technological applications

(4) They are very less versatile.

Advantages of Type II

(1) They can remain superconducting even in very strong magnetic fields.

(2) Many Type-II superconductors have comparatively higher transition temperatures.

(3) They can carry large currents without loosing superconductivity.

(4) Because of their ability to work in strong magnetic fields, they are used in powerful electromagnets.

Disadvantages of Type II

(1) They do not completely expel the magnetic field; magnetic flux can partially penetrate the material.

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(2) They have two critical magnetic fields, which makes their behaviour more complicated.

(3) Type II superconductors are usually alloys or complex compounds, that are hard to prepare.

(4) These are sensitive to changes in temperature and magnetic field strengths.

(5) They obey the Meissner effect partially.

Applications of Type I

(1) These are used in MRI machines which are used to generate strong magnetic fields for detailed medical imaging.

(2) These are used in Maglev Trains, which help the train to float above the tracks, allowing it to levitate and move at high speeds.

(3) These are used to produce the superconducting magnets which are used in a variety of applications.

(4) The superconducting cables made from Type-1 superconductors helps in transmitting electric power over large distances with minimal loss.

(5) These help in making good and highly sensitive

sensors which help in detecting tiny magnetic fields.

Applications of Type-II

① Cables made from Type-II superconductors are used for power transmission because of reduction in power loss.

② These are used to produce very large magnetic fields. These strong magnetic fields are used in MRI, CT etc.

③ These are used in construction of superconducting magnets which helps in accelerating particles at high speed.

④ These play an integral role in the development of superconducting qubits, which are building blocks of quantum computers.

⑤ These are used to levitate and propel the transportation medium above the track, resulting in less friction and less noise.